Magnetic Cloud Field Intensities and Solar Wind Velocities

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Abstract

For the sets of magnetic clouds studied in this work we have shown that there is a general relationship between their magnetic fields strength and velocities, with a clear tendency that the faster the speed of the cloud the higher the magnetic field. This result may involve an intrinsic property of magnetic clouds and also a geophysical consequence. The relatively low field strengths at low velocities is presumably the cause of the lack of intense storms during low speed ejecta. There is also an indication that this type of behavior is peculiar for magnetic clouds, whereas other types of non cloud-driver gas events do not seem to show a similar relationship, at least for the data studied in this paper. We suggest that an intrinsic magnetic field/speed relationship for magnetic clouds, as that obtained in our present study, could be associated with the cloud release and acceleration mechanism at the sun. This suggestion is based on a recent computer simulational work that supports our results.

Introduction.

It has been well established that major ($D_{st} \leq$ 100" nT) magnetic storms are associated with fast Coronal Mass Ejections (CMEs) coming from the sun from both during solar maximum (Gonzalez and Tsurutani, 1987; Tsurutani et al., 1988; Gosling et al., 1991; Gonzalez et al. 1994) and the descending phase of the solar cycle (Tsurutani et al. 1995). The energy transfer mechanism from the solar wind to the magnetosphere appears to be magnetic reconnection between the interplanetary and the earth's magnetic fields. The interplanetary dawn-dusk electric field, is given by $\mathbf{v} \times \mathbf{B_s}$ governs this process (Dungey, 1961). In the above expression, $\mathbf{v}$ is the solar wind velocity and $\mathbf{B_s}$ is the southward component of the interplanetary magnetic field (IMF). Gonzalez and Tsurutani (1987) have established empirically that the interplanetary electric field must be greater than 5 mV/m for longer than 3 hours to create a $D_{st} \leq -100$ nT magnetic storm. This corresponds to a southward field component larger than 12.5 nT for a solar wind speed of ≈ 400 Km/s.

Although the positive correlation between fast CMEs and magnetic storms have been stressed and is reasonably well understood, little attention has been paid to the opposite question, why don't slow CMEs lead to magnetic storms? Since this question involves the role of the magnetic field of the CME, it leads to a more general question, namely how are the CME's speed and magnetic field related to each other? These are the questions we wish to address in this letter.

If the speed of the solar ejecta is less than the upstream slow solar wind plus the magnetosonic wave's phase velocity, a fast forward shock will not form at the leading (antisunward) edge of the ejecta, and there will not be compressed sheath fields. On tilt' ot}l(rl~:ill(l. ollellligllt" ask "why can't the ejecta themselves have fields intense enough to create magnetic storms with intensities $D_{st} \leq -100$ nT"?. Tsurutani et al.(1992) have shown examples of great ($D_{st} \leq -250$ nT) magnetic storms that were caused by magnetic clouds with total field intensities of ≈ 25 nT and ≈ 35 nT (from which more than 90% of the intensity were in the B_s component). In both cases the velocities of the ejecta at 1 AU were "fast" (550 Km/s and 600 Km/s) but certainly not exceptional.

Method of Data Analysis.

To address this issue first we use magnetic cloud events. Magnetic clouds (Klein and Burlaga, 1982) are those portions of CMEs where there are strong north-south deviations in the field. It is thought (Farrugia et al., [1997], and references therein) that clouds are giant flux ropes formed by field aligned currents. The B_s component of the cloud has typically an amplitude that represents a substantial fraction of the total IMF intensity. For example, for the intense and superintense storms studied by Tsurutani et al.(1988) and Tsurutani et al.(1992), the magnetic clouds responsible for about half of the storm events had their B_s fields with intensities of 70% or more of the total IMF intensity. This fact justifies why magnetic clouds with strong magnetic fields have typically strong B_s components and therefore cause intense storms.

We have chosen to examine previously published magnetic cloud events because their identification exists in the literature and the public has the opportunity to examine the events in detail. We use the magnetic cloud events identified in Klein and Burlaga (1982); Burlaga et al. (1987); Tsurutani et al.(1988; 1992), Burlaga et al. (1996) and Farrugia et al. (1997). There are 19 events in total and all of them were observed at ≈ 1 AU. For each event we record the peak solar wind speed and the peak magnetic field values during the interval of the cloud events, using the plasma and magnetic field instrumentation on board of the spacecraft (a variety of space missions). The data have been acquired from the NSSDC web.

Then, we obtained a second and independent set of clouds in the following way. We took the whole year of 1979, for which a full set of plasma and magnetic field data was recorded by the ISEE-3 satellite, and identified the driver gas events using the criteria discussed by Zwickl et al. (1983) and Tsurutani et al.(1988). These events were divided in two subsets, one including only clear magnetic clouds, involving clear field rotations (e. g. Klein and Burlaga, 1982), and the other subset was formed with the remaining driver gas-non cloud events. For the first subset we obtained 13 events and for the second one 24 events. All these two types of events followed fast forward shocks, as identified by Smith et al. (1986) for the ISEE-3 interval.

As for the first set of clouds, we also performed the same study for the peak values of the solar wind speed and the magnetic fields within the intervals of these two subsets of events.

It is important to point out that the first set of magnetic clouds involve more intense events (higher B and v values) than those existing in the subset of the ISEE-3 events, and also caused more intense magnetic storms.

Results.

The magnetic cloud intensity versus speed for each of the 19 events of the first set of clouds is shown in Figure 1, in a scatter-plot format. A linear regression fit is added to the plot. The correlation coefficient is 0.85 and the linear regression line gives,

$$B_{peak}(nT) = 0.05\, v_{peak}(Km/s) - 2.01$$

Figure 2 shows a similar plot for the second set of clouds, for the 1979 driver gas-clear cloud events, and Figure 3 refers to the combined data set of those plotted in Figures 1 and 2, namely involving 32 clouds, both with fairly similar correlation coefficients to that of Figure 1.

From Figure 3, we note that at cloud velocities of $v \approx 400$ Km/s, the field magnitudes can be 15 to 20 nT, which could have a B_s component comparable to the value expected from the Gonzalez and Tsurutani (1987) criteria, discussed in the Introduction.

There is a clear tendency in these figures that the faster the speed of the cloud the higher the magnetic field. The highest velocity ejecta ever measured was in the August 1972 event. The velocity at 1 AU was around 1500 km/s. At 2.2 AU from the sun, Pioneer 10 measured a peak magnetic field of about 16 nT within a magnetic cloud event, as identified by Tsurutani et al.(1992) and discussed by Tsurutani and Gonzalez(1992). If one assumes a $r^{-1.7}$ radial dependence of the field (Rosemberg et al., 1978), this would correspond to about 60 nT field at 1 AU. these magnetic field and corresponding speed values fit the general trend of Figure 1 (since this figure refers more to very intense events). On the other hand, the magnetic cloud event of Jan 10, 1997, with peak values of about 15 nT and 480 Km/s, fits fairly well the trend shown in Figure 3, that includes more moderate intensity events.

Figure 4 refers to the ISEE-3 subset of driver gas-non cloud events. One can see that this plot is largely scattered, without any clear trend for a relationship between the peak values of the magnetic field and the solar wind speed. One can speculate that this set of events could still include clouds that were crossed by the satellite far from their center, for which a rotation in the field was not observed. In such a case much lower B fields are expected for a similar v value of the cloud. It is possible that other driver gas structures could be involved in Figure 4, and deserve a detailed investigation.

Discussion and Conclusions.

We have shown a general relationship between magnetic cloud field strength and velocities that may involve an intrinsic property of magnetic clouds and also a geophysical consequence. There is a clear tendency that the faster the speed of the cloud the higher the magnetic field. The relatively low field strengths at low velocities is presumably the cause of the lack of intense storms during low speed ejecta.

There is also an indication that this type of behavior is peculiar for magnetic clouds, whereas other types of non cloud-driver gas events do not seem to show a similar relationship.

At this time, the physical causes of the reported relationship between the magnetic field and plasma speed of the magnetic clouds are uncertain. Compression of the cloud is certainly occurring. Thus, it is possible that in some cases the field increases can be accounted for by such an effect.

Another possibility is that this relationship may be associated with the CME release and acceleration mechanisms at the sun. For example, a recent self-consistent numerical MHD simulation study (Wu et al., 1997) shows that the radial velocity of the flux rope erupting from a helmet streamer depends on the strength of the azimuthal component of the magnetic field of the flux rope, in a way consistent with the magnetic cloud

$B - v$ relationship shown in this paper. A detailed parametric study of this kind of simulational work is currently under way.

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Figure Captions

Figure 1. Scatter plot for B_{peak} versus v_{peak} for the first set of 19 magnetic clouds, taken from several references (see text), involving clouds that caused intense and very intense magnetic storms.

Figure 2. Scatter plot for B_{peak} versus v_{peak} for the second set of 13 magnetic clouds, as measured by the ISEE-3 satellite in 1979. All events followed fast forward shocks and involve clouds that caused some intense but mostly moderate magnetic storms.

Figure 3. Scatter plot for the combination of the two independent sets of clouds shown in Figures 1 and 2.

Figure 4. Driver gas events that did not involve clouds with clear field rotations (see text) and that also followed fast forward shocks in 1979, as measured by the ISEE3 satellite.

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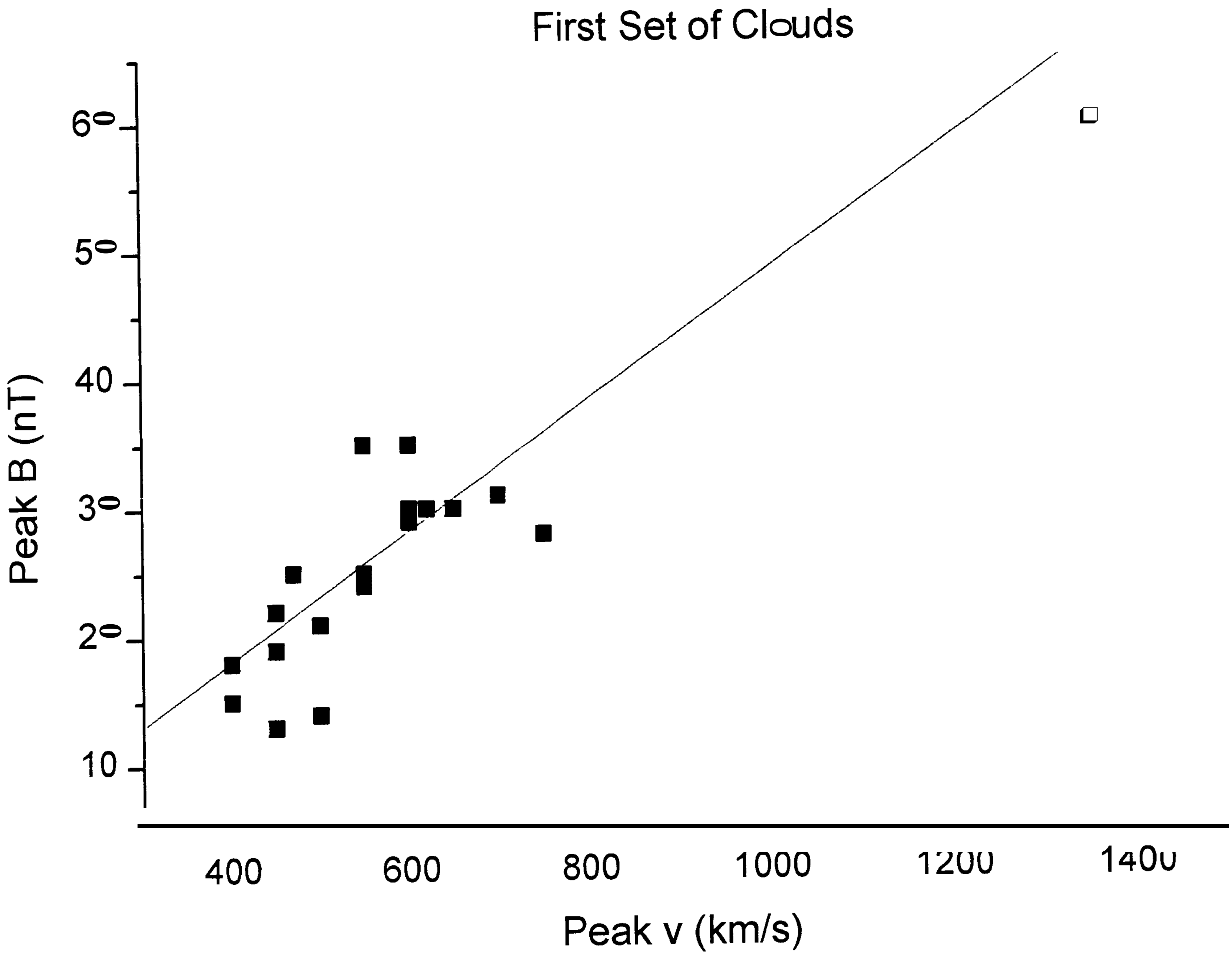

First Set of Clouds
Peak B (nT)
60
50
40
30
20
10
400
600
800
1000
1200
1400
Peak v (km/s)

Figure 1

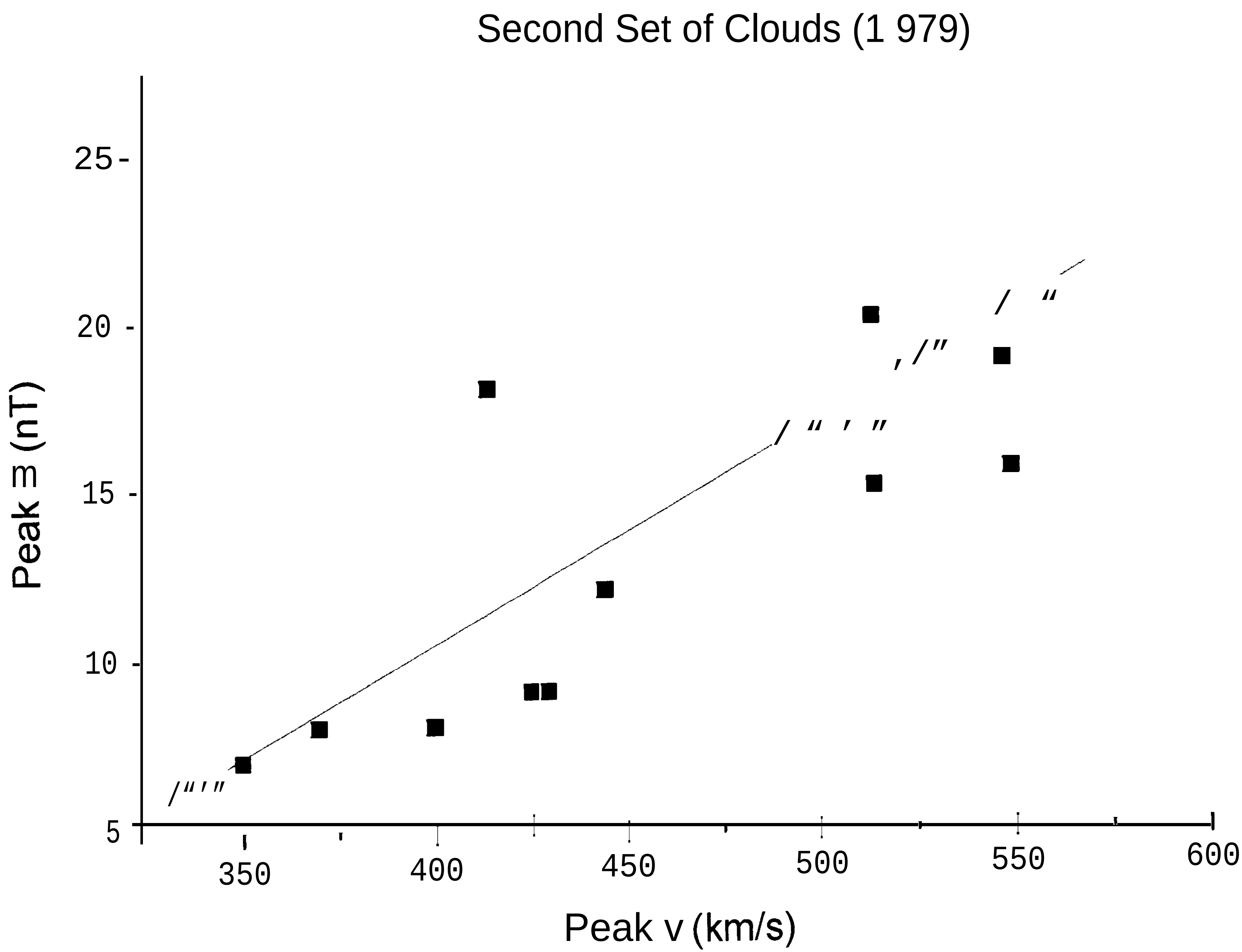
Second Set of Clouds (1 979)
25
20
15
10
5
Peak B (nT)
350
400
450
500
550
600
Peak v (km/s)

Figure 2

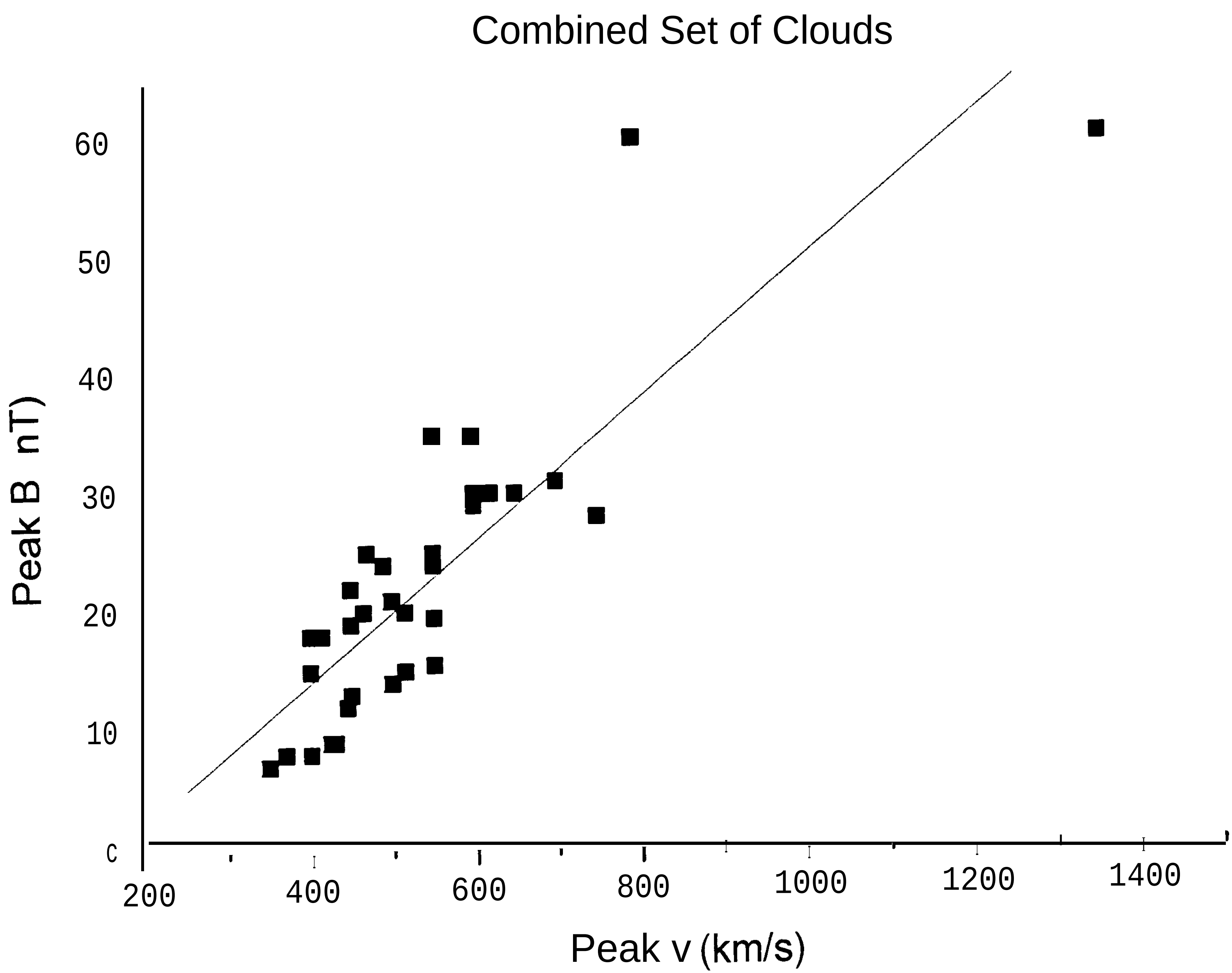
Combined Set of Clouds
Peak B nT)
60
50
40
30
20
10
C
200
400
600
800
1000
1200
1400
Peak v (km/s)

Figure 3

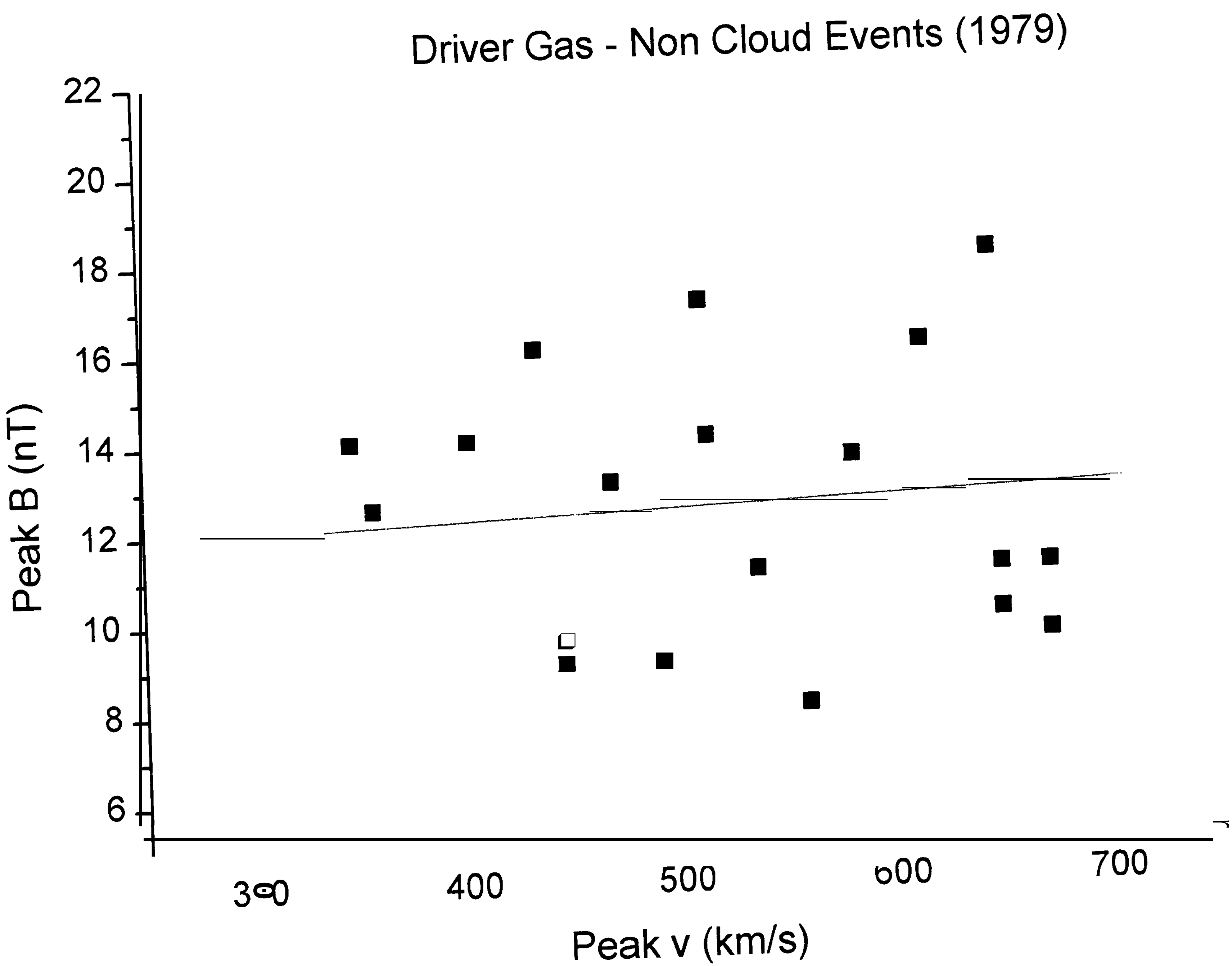
Driver Gas - Non Cloud Events (1979)
22
20
18
16
14
12
10
8
6
Peak B (nT)
300
400
500
600
700
Peak v (km/s)

Figure 4